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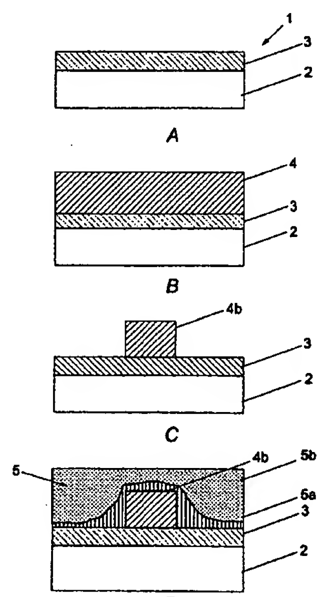
(54) Title: OPTICAL WAVEGUIDE WITH A COMPOSITE CLADDING LAYER AND METHOD OF FABRICATION THEREOF



(57) Abstract: An optical waveguide (1) with a composite cladding layer (5) comprises a substrate (2), a waveguide core (4b) formed on the substrate (2) and at least one upper cladding layer (5a, 5b) embedding said waveguide core (4b). The composite cladding layer (5) consists of a cladding portion (5a) formed in proximity to the waveguide channel core (4b) with a first composition and at least one cladding outer portion (5b) which substantially embeds said first portion (5a) and which has a second composition. The composition of each of the cladding interface layer (5a) and the cladding outer layer (5b) is selected such that their refractive indices are substantially equal whilst their other characteristics, for example, the temperature range over which they consolidate and soften differ.

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OPTICAL WAVEGUIDE WITH A COMPOSITE CLADDING LAYER AND METHOD OF FABRICATION THEREOF

This invention relates to an optical waveguide with a composite cladding and to a method of fabricating such a waveguide. In particular, the invention relates to an optical waveguide in which a cladding layer with a structured composition embeds a waveguide core, the cladding composition being varied with the depth of the cladding layer.

Planar optical waveguides are usually fabricated by forming several layers on top of a substrate, usually a silica wafer. The layers can be deposited by a variety of techniques, for example, plasma enhanced chemical vapour deposition (PECVD), low pressure chemical vapour deposition (LPCVD), and flame hydrolysis deposition (FHD). In the FHD fabrication process, the layers which make up the waveguide are first deposited as a layer of fine glass particles or "soot". The soot is subsequently heated in situ so that the particles fuse to form a consolidated glass layer.

The composition of each layer of the waveguide is usually selected so that certain desirable

characteristics are obtained. For example, so that the refractive index of the layer is uniform within the layer and/or matches the refractive index of other layers of the waveguide. Another desirable characteristic is for the coefficient of expansion of each layer to match that of the substrate and/or underlying layer. This minimises the amount of warpage that occurs as the waveguide is heated during its fabrication and post-fabrication processing.

Once deposited, a glass layer is heated so that it consolidates into a denser glass layer. Individual layers may be consolidated immediately after they are deposited or several layers may be deposited and consolidated together. If a layer is heated to a sufficiently high temperature in excess of its consolidation temperature, the viscosity of the consolidated layer is reduced until eventually the glass is able to flow. The smoother the surface of any layer of the waveguide, the less light is scattered at that surface. Thus, heating a layer to its softening temperature for a period of time is desirable if a high-quality waveguide is to be fabricated.

During the consolidation of a layer a temperature cycle is used in which at one stage the layer is heated to the "softening" temperature, which is significantly higher than the actual consolidation temperature. This enhanced temperature stage ensures that the glass forming the layer is sufficiently softened to flow and form a relatively smooth and level layer.

To ensure that the underlying layers are not deformed during the consolidation and/or softening of subsequent layers, the consolidation and softening temperatures of each subsequent layer are usually less than the

softening temperature of the underlying layer.

It is desirable, moreover, for the full consolidation of any overlying layer not to occur before the underlying layer has fully consolidated as this could potentially result in gas expelled from the lower layer being trapped under the overlying consolidated layer. Such "outgassing" occurs as the deposited soot layer begins to consolidate and the open network of pores formed by the deposited soot begins to collapse. The density of the glass layer is increased during its consolidation phase as any gas pockets are expelled.

If a layer becomes fully consolidated and further outgassing occurs in the underlying layer, the gas is trapped beneath the consolidated layer. Moreover, in waveguide devices such as Y-branch splitters and arrayed waveguide gratings (AWGs), narrow junctions with gaps of the order of 1 micron are formed where, for example, two waveguides meet and gas can become trapped in such gaps if the pore network of any cladding layer collapses prematurely.

To ensure that gas is not trapped in such regions as the glass consolidates, the cladding is usually deposited in multiple stages using a slowly rising temperature gradient. However, this greatly increases the complexity of the cladding stage of the waveguide fabrication. It is therefore desirable if a waveguide can be fabricated by depositing several layers and subsequently heating these layers together in a single consolidation stage.

To achieve high quality waveguides which can be consolidated in such a manner it is desirable for the composition of each layer to be carefully selected so

that its consolidation and softening temperatures are controlled. Also, multimode devices which have large waveguide geometries (>10 μm) require thick cladding layers which are also susceptible to gas trapping. Large aspect ratio devices can also be encountered for narrow slot devices; e.g. couplers with 8 μm deep waveguides and 1 μm edge to edge spacing. Surface relief gratings also require the 'filling' of narrow corrugations.

The present invention seeks to obviate or mitigate the aforementioned disadvantages by providing a waveguide with a graded, or composite cladding layer.

A first aspect of the invention seeks to provide an optical waveguide with a composite cladding layer. A second aspect of the invention seeks to provide a method of fabricating an optical waveguide with a composite cladding layer.

According to the first aspect of the invention, an optical waveguide is provided having

a substrate;

a waveguide core formed on the substrate and embedded by a cladding layer, wherein the cladding layer composition is varied so that the composition of a cladding interface portion located in the proximity of an interface between the waveguide core and the cladding is different from the composition of at least one cladding outer portion.

Preferably, the consolidation temperature of the cladding interface portion is lower than the consolidation temperature of the said at least one cladding outer portion.

More preferably, the softening temperature of the cladding interface portion is lower than the consolidation temperature of the said as least one cladding outer portion.

Preferably, said at least one cladding outer portion embeds said cladding interface portion.

The cladding layer composition may be varied by changing the concentration of at least one dopant ion species in the cladding layer.

Preferably, the dopant concentration of the cladding layer varies as a function of distance from the substrate.

More preferably, the dopant concentration of the cladding layer varies approximately as a function of distance from the interface between the cladding layer and the waveguide core.

The substrate may be a silicon wafer. The substrate may further comprise at least one intermediate layer formed thereon. At least one intermediate layer may be a cladding layer. Preferably, at least one intermediate layer is a buffer layer which comprises a thermally oxidised layer of the substrate.

The cladding layer may be doped at least one ion species taken from the group consisting of: a transition element, a rare earth ion species and/or a heavy metal ion species.

Preferably, the cladding layer is doped with at least one ion species taken from the group consisting of:
phosphorus, boron, titanium, tantalum, aluminium,

lanthanum, niobium, and/or zirconium.

The volume of the cladding interface portion may be substantially less than the volume of said at least one cladding outer portion.

Preferably, the depth of the cladding interface portion upon the substrate is substantially less than the maximum depth of the said at least one cladding outer portion.

The cladding layer may be doped with Boron and Phosphorus. Preferably, the relative dopant concentrations of Boron and Phosphorus in the cladding interface portion and the cladding outer portion provide a homogeneous refractive index throughout the cladding layer.

Preferably, the coefficient of thermal expansion of the cladding layer is substantially the same as the coefficient of thermal expansion of the substrate.

Preferably, the cladding layer composition is smoothly varied between said cladding interface portion and said at least one cladding outer portion.

According to a second aspect of the invention, a method for fabricating an optical waveguide is provided, the method having the steps of:

forming a substrate;

forming a waveguide core on the substrate; and

forming a cladding layer to embed said waveguide core wherein the cladding layer composition is varied so that the composition of a cladding interface portion located in the proximity of an interface between the waveguide core and the cladding layer is different from

the composition of at least one cladding outer portion.

The step of forming said substrate may include the step of forming an intermediate layer on said substrate. The intermediate layer so formed is preferably a buffer layer.

The cladding layer may be formed by depositing a particulate cladding soot and subsequently consolidating the cladding soot.

Preferably, the cladding layer forming the cladding interface portion is not consolidated before the said at least one cladding outer portion is deposited.

Preferably, the cladding layer is consolidated in a single process step.

The cladding interface portion may be at or above its softening temperature when the said at least one cladding outer portion reaches its consolidation temperature.

The consolidation temperature of the cladding interface portion is lower than the consolidation temperature of the said at least one cladding outer portion.

The waveguide core and/or cladding are deposited using a flame hydrolysis deposition process and/or a plasma enhanced chemical vapour deposition process and/or a low pressure chemical vapour deposition process.

At least one portion of said cladding layer may be doped with at least one dopant ion species taken from the group consisting of:

a transition element, a rare earth element and/or

a heavy metal element.

Preferably, at least one portion of said cladding layer is doped with at least one dopant ion species taken from the group consisting of:

phosphorus, boron, titanium, tantalum, aluminium, lanthanum, niobium, zirconium.

Preferably, the concentrations of the selected dopant ion species provide a refractive index for the buffer layer and cladding interface layer which differs from the refractive index of the waveguide core by between 0.2-2%.

Preferably, during the consolidation of the cladding layer, the consolidation conditions include a stage where the temperature remains above the softening temperature of the cladding interface portion.

The present invention will be further illustrated by way of example, with reference to the accompanying drawings in which:-

Fig 1 is a flow chart illustrating the fabrication steps of an optical waveguide according to a preferred embodiment of the invention;

Figs 2A to 2D are schematic diagrams showing the formation of an optical waveguide according to a preferred embodiment of the invention;

Fig 3 illustrates the variation of the refractive index of the dopants TiO_2, Al_2O_3, GeO_2, P_2O_5, B_2O_3, and F as a function of the dopant concentration;

Fig 4 illustrates how the coefficient of expansion of

an SiO_2 layer varies as the dopant concentration of GeO_2, P_2O_5, B_2O_3 and TO_2 varies;

Fig 5 illustrates the variation of the softening temperature of the dopant concentration of GeO_2, P_2O_5, B_2O_3;

Fig 6 illustrates how the concentration of dopants varies within the cladding layer in one embodiment of the invention;

Fig 7 illustrates how the consolidation and softening temperatures of the cladding layer and core layer vary in one embodiment of the invention; and

Fig 8 illustrates how the temperature cycle varies during the fabrication of the cladding layer according to one embodiment of the invention.

As illustrated in Figs 1 and 2, in one embodiment of the invention, an optical waveguide 1 has a composite cladding layer 5 embedding a waveguide core 4b. The waveguide 1 is fabricated in a series of steps as is shown in Fig 1.

Referring now to Fig 2A, an intermediate layer 3, for example a buffer or under-cladding layer, is formed on top of a substrate 2. In this example, a SiO_2 buffer layer 3 is formed by thermally oxidising a silicon substrate 2. Alternatively, more than one intermediate layer 3 may be formed by any suitable fabrication process.

Fig 2B sketches how a core layer 4 is formed on top of the buffer layer 3. Suitable fabrication processes for the core layer 4 and/or the buffer layer 3 include, for

example, a flame hydrolysis deposition process (FHD). In the FHD process, a soot layer of fine, particulate glass material(s) is deposited. Other suitable deposition processes may be used including, for example, plasma enhanced chemical vapour deposition (PECVD) and low pressure chemical vapour deposition (LPCVD) or a combination of deposition processes. The deposited layers are then consolidated either before the next layer is deposited or subsequently. Suitable consolidation processes include heating the optical waveguide 1 in a furnace or repassing an FHD burner flame over the deposited soot so that the soot layer consolidates.

The layers of the optical waveguide 1 typically include glass materials such as, for example, germanium and/or silicon oxides, in particular GeO_2 and/or SiO_2.

In one embodiment of the invention, the glass materials are doped during the deposition stage. Typical dopants, chosen for their effect on the thermal characteristics, refractive index and coefficient of expansion of the layer are selected quantities of, for example, boron, phosphorus, and/or titanium compounds (B_2O_3, P_2O_5, TiO_2). Certain characteristics of the glass are enhanced by introducing other transition elements and/or heavier dopant species, such as rare earths and/or heavy metals, which may be introduced using specialised techniques, for example an aerosol doping technique such as disclosed in United Kingdom Patent Application No.9902476.2. Other suitable dopants which produce desirable properties include, for example, tantalum, aluminium, lanthanum, niobium, and/or zirconium.

Fig 2C illustrates how a waveguide core 4b is formed by

removing unwanted portions 4a of the core layer 4 using a suitable etching technique, for example photolithographic process(es) and dry etching. The remaining core layer 4 forms the waveguide core 4b.

Fig 2D sketches how the waveguide core 4b is then embedded in a cladding layer 5. To achieve certain desirable characteristics, the composition of the cladding layer 5 is varied so that it has a composite structure. It is desirable for the composition to be varied smoothly in the invention, but alternatively, the composition may be varied more abruptly. The cladding layer 5 is formed generally by depositing and consolidating a glass material.

Any suitable deposition process, for example FHD, PECVD, LPCVD, is used to deposit a cladding layer 5 of glass material about the waveguide core 4b. The cladding layer 5 may be deposited in one stage or more than one stage, and the deposition may be varied smoothly or abruptly between stages or within any one stage. A cladding interface portion 5a has a substantially consistent composition which differs from a the composition of the cladding outer portion 5b. Additional cladding portions may be provided, for example, by a transition region between the two cladding portions.

In one embodiment of the invention, glass material forming the cladding interface portion 5a is deposited about the waveguide core 4b and over a part of the surrounding underlying surface presented by the substrate 2 or the buffer layer 3 to form a cladding interface portion. For example, a soot layer of suitable glass cladding material can be deposited around the core waveguide 4b using FHD to form the

cladding interface portion 5a.

The composition of the cladding is varied during the deposition process, for example, by varying the concentration of dopants within the glass material, so that at least one cladding outer portion 5b is formed with a composition differing from that of the cladding interface portion 5a. Using a FHD process, the cladding composition is varied during the deposition stage. The dopant concentration is varied in relation to the depth of the cladding layer 5 and/or in relation to the proximity of the waveguide core 4b.

By varying the composition of the cladding layer 5 by introducing dopants, the cladding layer 5 can be selected to possess certain desirable characteristics.

In this embodiment of the invention, the glass materials are boron and phosphorous doped SiO_2. However, other suitable glass materials may be used such as, for example, other silicon and/or germanium oxides, which may be doped to achieve certain desired properties. Dopants typically include transition elements and may further include rare earths and/or heavy metal elements. Dopants such as phosphorus, boron, titanium, tantalum, aluminium, lanthanum, niobium, and/or zirconium may be used. These dopants are usually chosen for their effect on the thermal characteristics, refractive index and coefficient of expansion.

In this embodiment of the invention, the glass materials are doped during the FHD deposition stage, however the doping may be achieved using other conventional methods.

The cladding layer 5 has the same refractive index as the refractive index of the buffer layer 3 in this embodiment of the invention and has a consolidation temperature T_C in the range lower than that of the softening temperature T_S of the waveguide core 4b.

Figs 3 to 5 illustrate the effect the dopant concentration has on the refractive index, coefficient of thermal expansion and softening temperatures of a silica cladding material. Fig 5 indicates that the higher the concentration of phosphorus, boron and germanium oxide in a layer, the lower the softening temperature. Fig. 3 sketches how the presence of such dopants also affects the refractive index of the cladding material: increasing the quantity of phosphorus and germanium oxide increases the refractive index, whereas the presence of boron oxide tends to reduce the refractive index.

By maintaining the relative concentrations of the selected dopant species constant, a substantially constant refractive index across the cladding layer 5 can be obtained. For example, by doping the cladding layer 5 with phosphorus and boron it is possible to reduce the sintering temperature and still maintain the refractive index close to or matching that of the buffer layer 3. Thus by increasing the phosphorus and boron levels in the cladding interface portion 5a the same refractive index as the buffer layer 3 is obtained but the cladding interface portion 5a has a lower sintering temperature than the sintering temperature of the buffer layer 3. This provides a smoother interface but also provides the advantage that the composite layer is less susceptible to gas trapping.

The cladding composition is thus selected so that each

of the cladding interface portion 5a and the cladding outer portion 5b have substantially the same refractive index and so that this refractive index matches the refractive index of the substrate 2 (or thermal oxide buffer layer 3). For example, the cladding layer 5 can be matched to the substrate/buffer layer so that the thermal expansion coefficients are substantially equal to 25 x 10^{-7}.

Referring now to Fig. 6, the concentration of dopants in the cladding layer 5 is varied so that the cladding material at the cladding interface portion 5a has the lowest consolidation temperature T_{5AC} whereas the consolidation temperature T_{5BS} of the cladding outer portion 5b is higher. Away from the immediate vicinity of the core 4b, the gradation of the cladding composition may be increased to vary the consolidation temperature as the cladding layer depth increases.

The thermal characteristics and conditions of the optical waveguide and its method of fabrication will now be discussed in more detail.

The temperatures to which the optical waveguide 1 is subjected to during the consolidation phase of the cladding layer 5 are varied at a rate determined by the composition of the cladding layer 5 and by the variation of the dopant concentrations as a function of depth within the optical waveguide 1.

During consolidation of the cladding layer 5, the temperature increases at such a rate as to ensure that the cladding outer portion 5b consolidates fully only once all gas trapped within the cladding interface portion 5a has been fully expelled. This prevents gas remaining in a partially consolidated layer from being

trapped by an overlying fully consolidated layer.

In one embodiment of the invention, the cladding interface portion 5a has a softening temperature of 1100°C whereas the remaining cladding portion 5b has a consolidation temperature of approx 1150°C. The cladding interface portion 5a is thus fully consolidated whilst the surrounding cladding outer portion 5b is still only partially consolidated.

Fig. 7 indicates how the softening temperatures and consolidation temperatures of each of the cladding portions 5a and 5b vary in relation to each other.

The cladding layer 5, core layer 4 and substrate 2 compositions are selected to ensure that the consolidation of any one of these does not cause any thermal deformation of the rest of the optical waveguide 1. Each of the cladding layer 5, core layer 4 and substrate 2 has a consolidation temperature which is lower than the softening temperature of the underlying portion. Alternatively, an additional cladding and/or buffer layers can be formed in between two layers of the waveguide.

The fabrication conditions for the cladding interface portion 5a formed around the waveguide core 4b, are provided below. These can be compared to the conditions for forming the cladding outer portion 5b. The cladding outer portion 5b has a composition substantially different from that of the first cladding portion 5a. The FHD conditions for forming the cladding portions 5a, 5b are as follows:-

Core/Clad Interface Portion (5a)		**Remaining Cladding Portion** (5b)	
Bubbler Gas	Flow Rate (sccm)	Bubbler Gas	Flow Rate (sccm)
$SiCl_4$	150	$SiCl_4$	150
PCL_3	90	PCL_3	73
BCl_3	32	BCl_3	26
Transport Gases	**Flow Rate**	**Transport Gases**	**Flow Rate**
$H_2:O_2$	2 $Lmin^{-1}$:4 $Lmin^{-1}$	$H_2:O_2$	2 $Lmin^{-1}$:4 $Lmin^{-1}$

The above flow rates are controlled so that the resulting composition of the cladding interface portion 5a produces a refractive index for the cladding interface portion 5a which is substantially the same as the refractive index of the cladding outer portion 5b. This refractive index is selected to substantially match the refractive index of the buffer layer 3.

The compositions of both the cladding interface portion 5a and the cladding outer portion 5b are controlled so that index matching can be achieved whilst minimising the potential for thermal deformation of the cladding layer 5 during the consolidation stage of fabrication.

Fig 8 illustrates a suitable temperature cycle according to the invention. In this example, during the consolidation process the temperature conditions are initially 650°C rising at 15°C min^{-1} to 850°C, and then further increasing to 1050°C at 5°C min^{-1}. The optical waveguide 1 remains substantially at 1050°C for approximately 60 minutes in an helium oxygen atmosphere

(0.6 L min^{-1} He and 0.2 L min^{-1} O_2). The temperature further rises to 1150°C min^{-1} and remains at this upper temperature for approximately 60 minutes before being cooled to 650°C at -5°C min^{-1}. To summarise, the temperature cycle is thus as follows:-

i) 650°C to 850°C at 15°C min^{-1}
ii) 850°C to 1050°C at 5°C min^{-1}
iii) 1050°C for 60 minutes
iv) 1050°C to 1150°C at 5°C min^{-1}
v) 1150°C for 60 minutes
vi) 1150°C to 650°C at - 5°C min^{-1}

The softening temperature is the temperature at which the viscosity of a consolidated layer is reduced sufficiently for the consolidated layer to begin to 'flow'. During fabrication of the optical waveguide 1, the softening temperatures of the cladding interface portion 5a and at least one cladding outer portion 5b are each controlled by the selection of suitable dopants and dopant concentrations.

The cladding interface portion 5a has a softening temperature T_{5AS} = 1100°C. The cladding outer portion 5b has a consolidation temperature T_{5BC} 1150°C which has been selected to exceed the softening temperature T_{5AS} of the cladding interface portion 5a by a preferred amount, 50°C.

If a temperature cycle such as Fig. 8 illustrates is used to consolidate the cladding layer 5, then by increasing the temperature from 600°C to 1100°C at 5°C min^{-1}, the cladding interface portion 5a consolidates first. This enables gas to be expelled through the overlying partially consolidated cladding outer portion 5b.

To prevent premature consolidation of the cladding outer portion 5b, the temperature range over which the cladding layer 5 is heated includes a suitable consolidation ramp rate of 5°C min^{-1}. This removes the possibility of any portion of the cladding interface portion 5a prematurely consolidating. Other means to promote pore collapse may also be used , for example, He gas may be included during the consolidation phase to promote core collapse.

The high temperatures required to consolidate the waveguide layers may be achieved by known techniques, for example, passing a burner flame from a flame hydrolysis burner over the deposited soot layer or by placing the waveguide wafer 1 in a suitable furnace.

While several embodiments of the present invention have been described and illustrated, it will be apparent to those skilled in the art once given this disclosure that various modifications, changes, improvements and variations may be made without departing from the spirit or scope of this invention.

For example, more than two cladding layers may be formed in the composite multi-layer cladding, and the composition of each cladding layer selected so that joint or separate consolidation can occur.

Any range given herein may be extended or altered without losing the effects sought, as will be apparent to the skilled person for an understanding of the teachings herein.

CLAIMS:

1. An optical waveguide (1) having:
a substrate (2);
a waveguide core (4b) formed on the substrate (2) and embedded by a cladding layer (5), wherein the composition of the cladding layer (5) is varied so that the composition of a cladding interface portion (5a) located in the proximity of an interface between the waveguide core (4b) and the cladding layer (5) is different from the composition of at least one cladding outer portion (5b).

2. An optical waveguide (1) as claimed in claim 1, wherein the consolidation temperature of the cladding interface portion (5a) is lower than the consolidation temperature of the said at least one cladding outer portion (5b).

3. An optical waveguide (1) as claimed in claim 1 or claim 2, wherein the softening temperature of the cladding interface portion (5a) is lower than the consolidation temperature of the said as least one cladding outer portion (5b).

4. An optical waveguide (1) as claimed in any preceding claim, wherein said at least one cladding outer portion (5b) embeds said cladding interface portion (5a).

5. An optical waveguide (1) as claimed in any preceding claim, wherein said cladding composition is varied by changing the concentration of at least one dopant ion species in the cladding layer (5).

6. An optical waveguide (1) as claimed in claim 5,

wherein the dopant concentration of the cladding layer (5) varies as a function of distance from the substrate (2).

7. An optical waveguide (1) as claimed in claim 6, wherein the dopant concentration of the cladding layer (5) varies approximately as a function of distance from the interface between the cladding layer (5) and the waveguide core (4b).

8. An optical waveguide (1) as claimed in any preceding claim, wherein said substrate (2) is a silicon wafer.

9. An optical waveguide (1) as claimed any preceding claim, wherein said substrate (2) further comprises at least one buffer layer (3) formed thereon.

10. An optical waveguide (1) as claimed in claim 9, wherein at least one of said at least one buffer layer (3) is a thermally oxidised layer of the substrate (2).

11. An optical waveguide (1) as claimed in any one of claims 5 to 10, wherein the cladding layer (5) is doped with at least one ion species taken from the group consisting of:

a transition element, a rare earth ion species and/or a heavy metal ion species.

12. An optical waveguide (1) as claimed in claim 11, wherein the cladding layer (5) is doped with at least one ion species taken from the group consisting of:

phosphorus, boron, titanium, tantalum, aluminium, lanthanum, niobium, and/or zirconium.

13. An optical waveguide (1) as claimed in any

preceding claim wherein the volume of the cladding interface portion (5a) is substantially less than the volume of said at least one cladding outer portion (5b).

14. An optical waveguide (1) as claimed in any preceding claim, wherein the depth of the cladding interface portion (5a) upon the substrate (2) substantially less than the maximum depth of the said at least one cladding outer portion (5b).

15. An optical waveguide (1) as claimed in any one of Claims 11 to 14, wherein the relative dopant concentrations of Boron and Phosphorus in the cladding interface portion (5a) and the cladding outer portion (5b) provide a homogeneous refractive index throughout the cladding layer.

16. An optical waveguide (1) as claimed in any preceding claim, wherein the coefficient of thermal expansion of the cladding layer (5) is substantially the same as the coefficient of thermal expansion of the substrate (2).

17. An optical waveguide (1) as claimed in any preceding claim, wherein said cladding composition is smoothly varied between said core/interface cladding portion (5a) and said at least one cladding outer portion (5b).

18. A method for fabricating an optical waveguide having the steps of:

forming a substrate (2);

forming a waveguide core (4b) on the substrate (2); and

forming a cladding layer (5) to embed said

waveguide core (4b) wherein the cladding composition is varied so that the composition of a cladding interface portion (5a) located in the proximity of an interface between the waveguide core (4b) and the cladding layer (5) is different from the composition of at least one cladding outer portion (5b).

19. A method as claimed in Claim 18, wherein the step of forming said substrate (2) includes the step of forming an buffer layer (3) on said substrate.

20. A method as claimed in Claim 18 or Claim 19, wherein the cladding layer (5) is formed by depositing a particulate cladding soot and subsequently consolidating the cladding soot.

21. A method as claimed in Claim 20, wherein the cladding layer (5) forming the cladding interface portion (5a) is not consolidated before the said at least one cladding outer portion (5b) is deposited.

22. A method as claimed in Claim 21, wherein the cladding layer (5) is consolidated in a single process step.

23. A method as claimed in Claim 22, wherein the cladding interface portion (5a) is at or above its softening temperature when the said at least one cladding outer portion (5b) reaches its consolidation temperature.

24. A method as claimed in claim 23, wherein the consolidation temperature of the cladding interface portion (5a) is lower than the consolidation temperature of the said at least one cladding outer portion (5b).

25. A method as claimed in claim 23 to 24, wherein the waveguide core (4b) and/or cladding layer (5)are deposited using a flame hydrolysis deposition process and/or a plasma enhanced chemical vapour deposition process and/or a low pressure chemical vapour deposition process.

26. A method as claimed in any one of Claims 18 to 25, wherein in at least one portion of said cladding layer (5) is doped with at least one dopant ion species taken from the group consisting of:

a transition element, a rare earth element and/or a heavy metal element.

27. A method as claimed in claim 25, wherein at least one portion of said cladding layer (5) is doped with at least one dopant ion species taken from the group consisting of:

phosphorus, boron, titanium, tantalum, aluminium, lanthanum, niobium, zirconium.

28. A method as claimed in any one of claims 18 to 27, wherein the concentrations of the selected dopant ion provide a refractive index for the buffer layer (3) and cladding interface layer (5a) which differs from the refractive index of the waveguide core (4b) by between 0.2-2%.

29. A method as claimed in any one of claims 20 to 28, wherein during the consolidation stage of at least one portion of said cladding layer (5), the consolidation temperature conditions include a stage where the temperature remains above the softening temperature of the cladding interface portion.

30. An optical waveguide (1) with a cladding layer (5)

including at least two distinct portions (5a,5b) with different compositions as described substantially herein and with reference to the accompanying drawings.

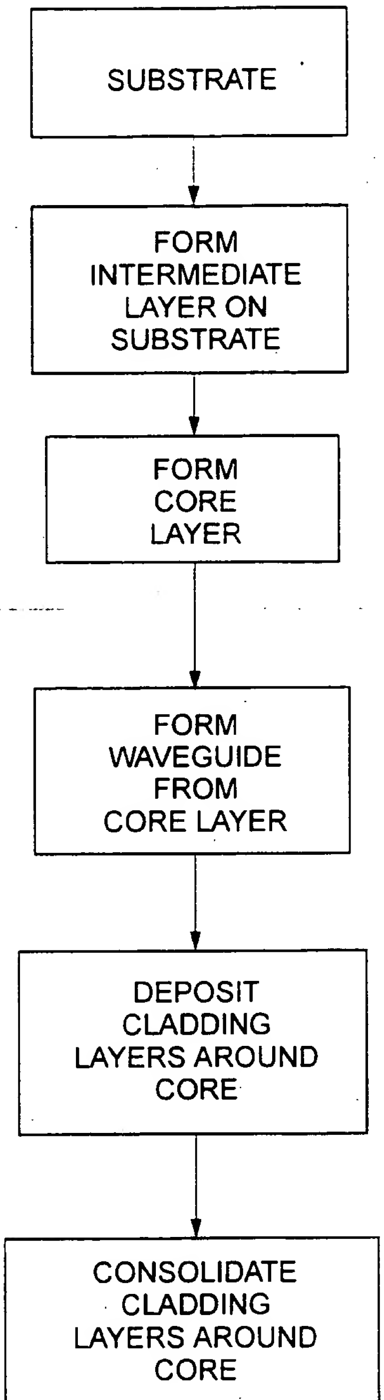

SUBSTRATE
FORM INTERMEDIATE LAYER ON SUBSTRATE
FORM CORE LAYER
FORM WAVEGUIDE FROM CORE LAYER
DEPOSIT CLADDING LAYERS AROUND CORE
CONSOLIDATE CLADDING LAYERS AROUND CORE

Fig. 1

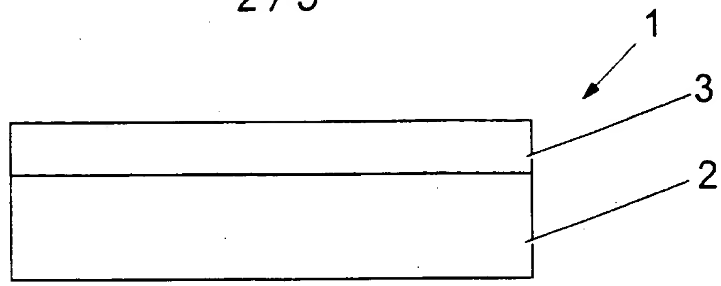


Fig. 2A

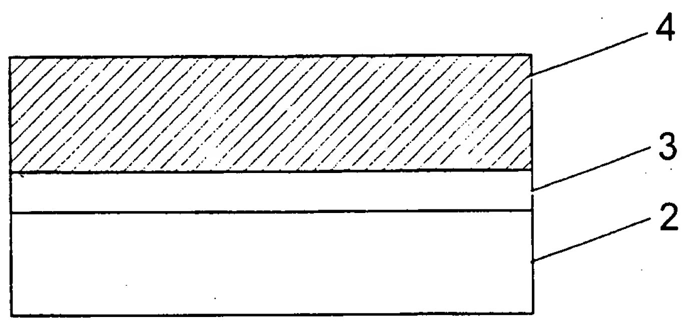


Fig. 2B

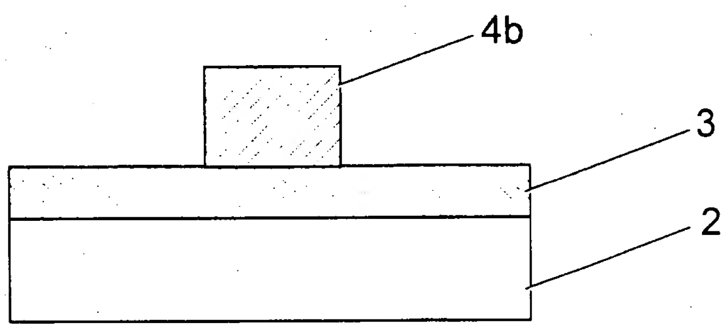


Fig. 2C

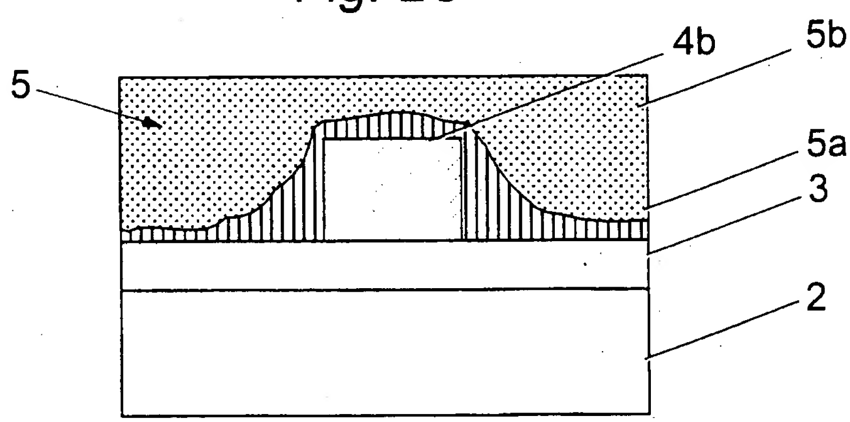


Fig. 2D

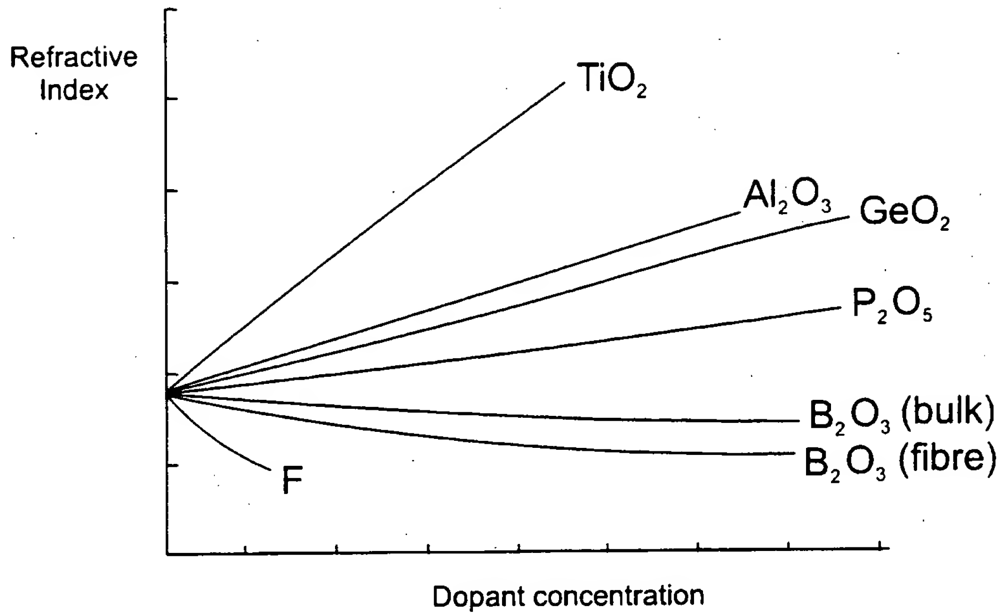

Refractive Index
TiO_2
Al_2O_3
GeO_2
P_2O_5
B_2O_3 (bulk)
B_2O_3 (fibre)
F
Dopant concentration

Fig. 3

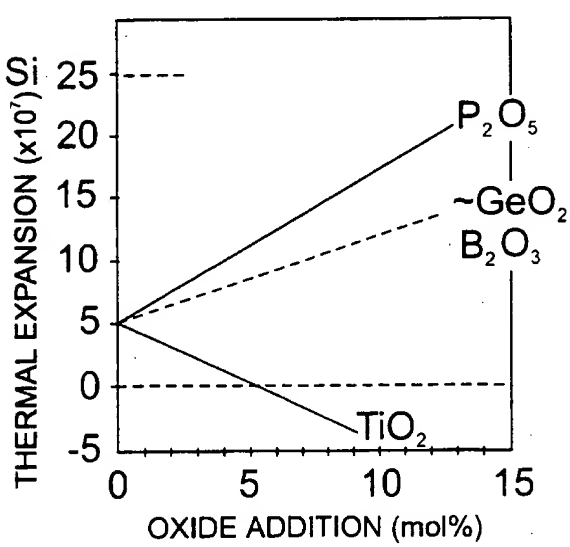
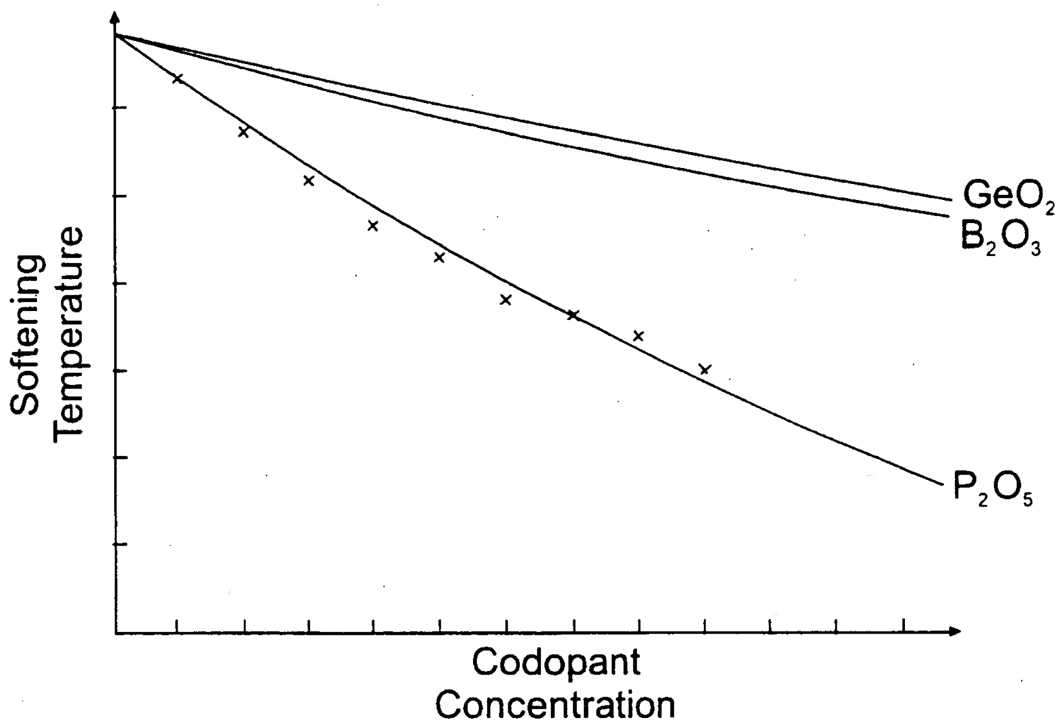
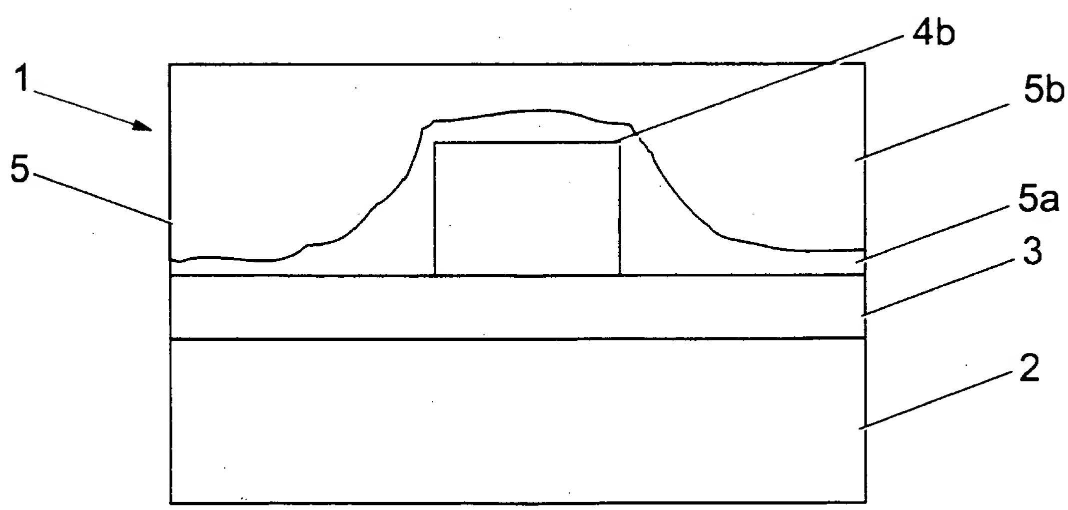

THERMAL EXPANSION (x10^7)
Si
25
20
15
10
5
0
-5
0
5
10
15
P_2O_5
~GeO_2
B_2O_3
TiO_2
OXIDE ADDITION (mol%)

Fig. 4



Softening Temperature
Codopant Concentration
GeO_2
B_2O_3
P_2O_5

Fig. 5



1
4b
5b
5
5a
3
2

Fig. 6

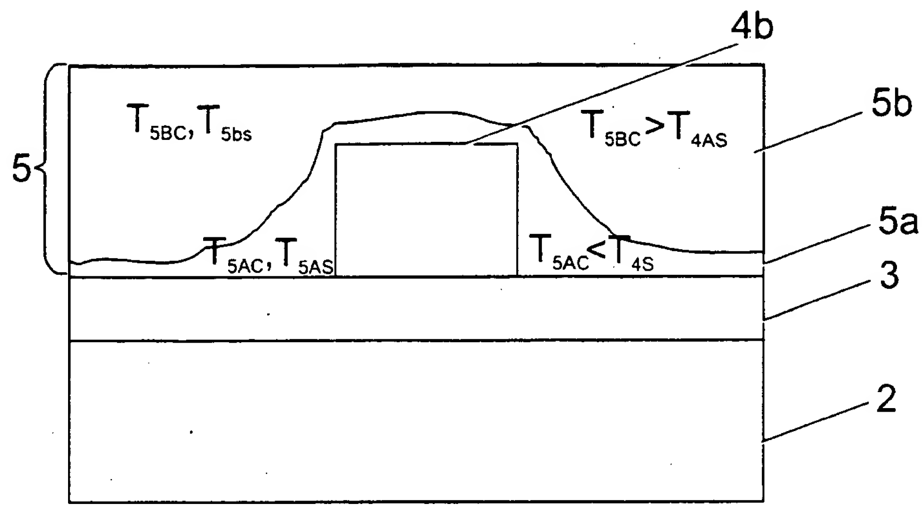

4b
5b
5a
3
2
5
T_{5BC}, T_{5bs}
$T_{5BC} > T_{4AS}$
T_{5AC}, T_{5AS}
$T_{5AC} < T_{4S}$

Fig. 7

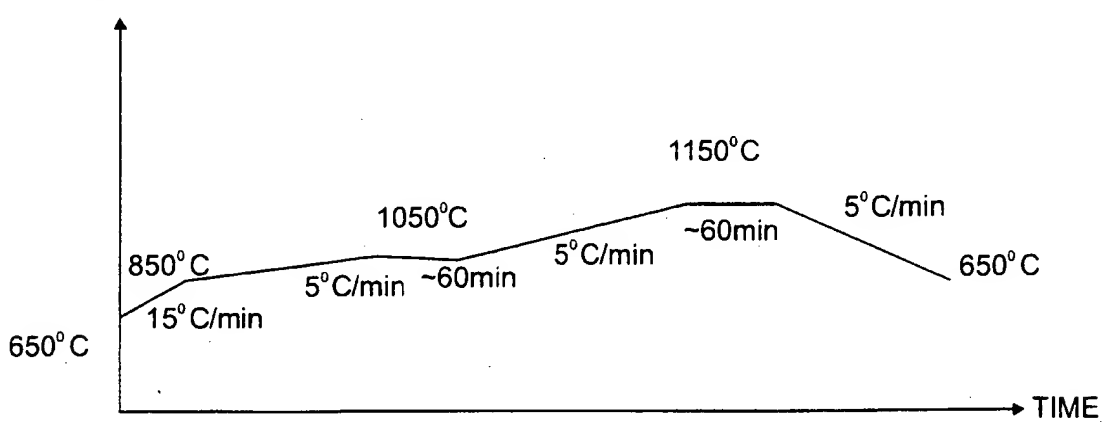

Temperature
1150°C
1050°C
5°C/min
850°C
~60min
5°C/min
~60min
5°C/min
650°C
15°C/min
650°C
TIME

Fig. 8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/03855

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B C03B C03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 322 744 A (HITACHI LTD) 5 July 1989 (1989-07-05) column 4, line 50 -column 5, line 10; figures 2A,2B,10B,11B column 7, line 3 - line 17	1,2,4-7, 9,11,12, 15,18, 20,22, 26,28,30
A	US 4 425 146 A (IZAWA TATSUO ET AL) 10 January 1984 (1984-01-10) figure 9	1,5
X	WO 93 16403 A (BRITISH TELECOMM) 19 August 1993 (1993-08-19) page 8, line 1 -page 9, line 6; figure 2	1,4-9, 11-15, 18-20, 26,30

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 March 2001	16/03/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ciarrocca, M

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INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/GB 00/03855

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 1996, no. 04, 30 April 1996 (1996-04-30) & JP 07 318734 A (HITACHI CABLE LTD), 8 December 1995 (1995-12-08) abstract ---	1,4-6,8, 11-14, 18,20, 21,26, 27,30
X	PATENT ABSTRACTS OF JAPAN vol. 017, no. 448 (P-1594), 17 August 1993 (1993-08-17) & JP 05 100123 A (FUJITSU LTD), 23 April 1993 (1993-04-23) abstract -----	1,4,13, 14,18, 20,30

1

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/03855

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			DE	69324670	T	09-09-1999
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			EP	0819955	A	21-01-1998
			EP	0819956	A	21-01-1998
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